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Acquisition of Capabilities through Systems-of-systems: Case Studies and Lessons from Naval Aviation

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Acquisition of Capabilities through Systems-of-systems: Case Studies and Lessons from Naval Aviation

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Abstract

The acquisition community in many nations faces novel challenges with the transition to systems-of-systems, capabilities-based solutions to meet military requirements. Much of the "tribal knowledge" and experience of those in acquisition, both in industry and government, has stemmed from platform-centred development strategies. It is questionable to what extent lessons from these can be applied to systems-of-systems acquisition. How does the acquisition expert trade off platform capabilities against the capabilities of a network of systems that might be composed of new and existing platforms used in new or old ways?

This paper presents case studies from past and present, illustrating such issues, and seeks to draw out lessons from experience that may be useful. It draws on many years of empirical research, undertaken with those involved in addressing such issues in the acquisition community.

Introduction

Much work in the acquisition community, in many nations, has been undertaken in recent years toward achieving enhanced military capabilities through the use of systems-of-systems, network-centric or -enabled capabilities and through life management of these. This work has been motivated by many different factors—evolving threats and military doctrines, changes in technology, force re-structuring, etc. Central to these efforts has been a desire to achieve interoperability of forces, allowing the deployment of capabilities that, hopefully, are more than the sum of their parts.

While much of this work has rightly focussed on the opportunities offered by new, notably digital, technologies, more prosaic (perhaps what could be seen as "old-fashioned") issues also have a significant impact. Capability depends on the interaction of all system components and their differing characteristics. In this paper, the effects of capabilities of such prosaic issues will be explored, with the focus on one of the oldest "systems-of-systems," the aircraft carrier and its aircraft. In a near century of evolution, the aircraft carrier and military aircraft have evolved both independently and together in the face of, and in response to, changing military needs. The success of their evolutionary ability means that they are still seen as providing important capabilities for the long term.

Aircraft and aircraft carriers form symbiotic system for the delivery of capability. A view of aircraft carriers as mere infrastructure, a floating runway and hangar for the aircraft it carries, misses much of its importance. In order to understand how to acquire such capabilities, we need to understand the interactions between the aircraft carrier and its aircraft. In this paper, the prosaic issues that matter in operating aircraft from ships will be illustrated. This is not to diminish the modern need for digital interoperability, etc., but rather to illustrate how matters such as simply being able to move aircraft around the deck and hangar of a ship in an effective manner can have significant effects on capability.

This paper examines the issue from the perspective of the United Kingdom’s Royal Navy and its experiences of deploying Short Take Off and Vertical Landing (STOVL) aircraft onboard its carrier fleet over several decades. Current acquisition policy in the UK is concerned with delivering capability using Through Life Capability Management (TLCM). This is defined as, “translating the requirements of Defence policy into an approved programme that delivers the required capabilities, through-life, across all Defence Lines of Development” (MoD, 2009).

The Defence Lines of Development (DLODs) allow for the co-ordination of the development of the different aspects of capability that are needed to create a real military capability. These aspects are:

- Training
- Equipment
- Personnel
- Information
- Concepts & Doctrine
- Organisation
- Infrastructure
- Logistics

It is only by addressing all the lines of development that the acquisition (and sustainment) community can effectively deliver capability to the UK armed forces, through the various force elements (ships, aircraft, army units, etc.), which are then used to create Joint Capability Packages. These are tailored by a force commander to undertake particular missions or tasks, taking into account coalition forces, threats and the overall operating environment. This is shown in Figure 1.

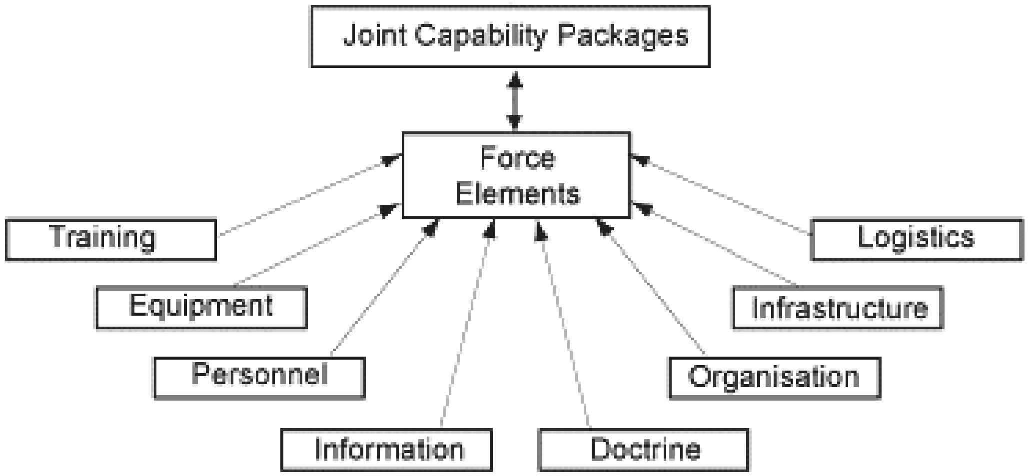

Figure 1. The Role of the UK Defence Lines of Development in the Creation of Capability

The DLODS can therefore be seen as being the primary constituents of capability and forms a useful analytical tool to understand the impact of differing ways of delivering capability. In this paper, we are concerned with the UK Royal Navy's use of STOVL aircraft from its carriers. An illustration of how the choice of STOVL aircraft can impact on the DLODs is shown in Figure 2.

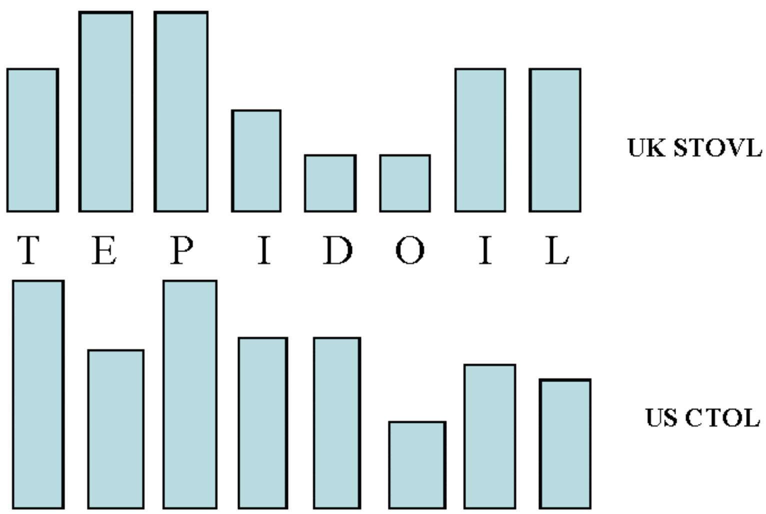

Figure 2. Comparison of UK and US Naval Strike Fighter Costs across the UK Defence Lines of Development
(Stanford, 2008)

This figure illustrates how, for the achievement of a given capability, the costs are allocated for the two examples across the DLODs, due both to the innate differences between two different types of aircraft and also to the differing operational employment of STOVL and CTOL aircraft. The UK STOVL aircraft training costs are lower than for the US aircraft, attributable to the needs of "cat and trap" landings at 140 knots on the US Navy supercarrier.

However, the lower warload of the UK STOVL aircraft may account for the higher overall equipment costs while the difference in costs attributable to doctrine is perhaps the most marked, reflecting the greater flexibility of the STOVL aircraft carrier and its aircraft.

While STOVL aircraft may be "easier" to integrate at one level with a ship (with no catapult or arrestor wires and the ability for STOVL aircraft to operate from smaller ships), what this example really illustrates is that the costs are distributed differently for a given capability depending on the nature of the systems used to deliver it. In the case of aircraft carriers and their aircraft, it is important to note that both are complex systems in their own right, with differing design, testing, manufacturing and support approaches. As Andrews (2003) has rightly pointed out, a ship does not have a prototype, unlike aircraft, and therefore, there is a need for the designer to ensure that it is "right first time." However, in the case of an aircraft carrier, it is only once it is operating aircraft, or when a new generation of aircraft are introduced, that it can be determined if the design was indeed right—and that while it may be right first time, it may not be right second time, with new aircraft onboard.

For the acquisition community, the issues attendant on developing and sustaining capability using ships and aircraft in combination present formidable challenges. While traditional approaches to designing them separately may be seen as less than ideal, the rest of this paper will explore how the acquisition process of the past has managed to achieve a large measure of success in doing this, despite being focussed largely around projects rather than overall capability.

Harrier and Invincible Class Experience and Design

One of the main "transformational" military technologies of the twentieth century was the development of aircraft to provide a new dimension to warfare. The impact of aircraft on naval warfare became apparent during World War II, notably in the great battles of the Pacific War, with Japan and the United States relying on aircraft and aircraft carriers as the centrepiece of their fleets. Post-1945, the aircraft carrier continued in this central role in major navies, and helicopters allowed the provision of air power to be extended to smaller vessels and lesser navies.

In the United Kingdom, attempts to sustain a viable force of major aircraft carriers foundered due to budgetary restrictions. Nevertheless, in order to retain a viable naval force, it was recognised (despite considerable inter-service debate) that some form of organic air power was still required to deliver the Royal Navy's key NATO role of anti-submarine warfare in the Eastern Atlantic. This was a highly complex environment with threats from Soviet submarines, surface combatants and aircraft (both land- and ship-based) requiring a mix of capabilities to be able to respond to them.

In order to meet these threats, the Royal Navy was largely forced to adapt the land-based Harrier STOVL strike aircraft to meet their needs. The ability of the Harrier to land on many types of ship had been demonstrated since 1963, from full-size aircraft carriers to the helicopter decks of cruisers. The adoption of the Harrier by the US Marine Corps during the 1970s had led to the regular use of the aircraft from the assault ships of the US Navy, although only those (LPH and LPD) with full flight decks and hangars had Harriers based on them.

The Royal Navy was already planning a fore of anti-submarine warfare (ASW) cruisers during the early 1970s, to operate helicopters only. However, the need for the ships to carry more than six helicopters to meet the submarine threat from the Soviet Union led to the adoption of a “through deck” layout for the ships, essentially a miniature aircraft carrier, and in many ways the same basic layout as the US Navy’s assault ships from which the Harrier was already operating. The recognition of the inability of surface-to-air missiles to fully meet the threat of “shadowing” reconnaissance aircraft of the Soviet Navy (providing targeting data for submarine launched anti-ship missiles) led the Royal Navy to push for the adoption of the Harrier to operate from the new class of ASW cruisers, with a small number of the aircraft operating alongside the helicopters. This led to the development of the British Aerospace (BAe) Sea Harrier, which first flew in 1978 (Brown & Moore, 2003).

However, the design of the ships, which became known as the Invincible class, was largely fixed before the decision to develop the Sea Harrier—HMS Invincible was laid down in 1973, while the Sea Harrier was not funded for development until 1978. This meant that, with the Sea Harrier being an adaptation of the land-based Harrier, neither the ship nor the aircraft was designed specifically for the other. For the ship, the hangar, flight deck, maintenance and stores (fuel, weapons, spares) facilities were all designed around the Sea King ASW helicopter. They were also designed “to have the ability to take future VSTOL” (i.e., STOVL) aircraft, with provision made for STOVL aircraft (in terms of some additional space being allocated and with the aircraft lifts) sized for STOVL aircraft. This latter assumed a generation of aircraft in advance of the Harrier, although it led to the assumption that such an aircraft would have similar dimensions to an earlier STOVL project, which had been cancelled while still under development in 1965: the Hawker Siddeley P.1154. The latter had been essentially a larger, faster, more powerful version of the Harrier concept (Andrews, 2009, February 12).

Adapting the Harrier for use in a maritime environment proved relatively straightforward, with new avionics and minor systems improvements in addition to a more noticeable new front fuselage. As the aircraft was relatively small, major modifications such as wing folding were not required, although the radome folded for maintenance access and to reduce the spotting factor. Tie-down lugs were added to the aircraft’s undercarriage to secure it to the deck, but, all told, “navalisation” added only an extra 100 pounds of weight. This low figure was largely attributable to the ability of the Sea Harrier to land vertically, so eliminating the need for strengthening to cope with arrested landings, as well as the aircraft’s ability to take-off without the need for catapulting, with similar structural “beefing up” obviated (Fozard, 1978).

In place of the catapult, one innovation allowed the Sea Harrier to operate at higher weights from aircraft carriers. This was the “ski jump” ramp, an upwardly curved addition to the end of the flight deck runway that enabled the Sea Harrier to take-off at either lower airspeeds or at higher weights for a given deck run than a “flat deck” take-off. The ramp also offered safety benefits, as it meant that the Sea Harrier should almost always be launched on an upwards trajectory even if the bows of the ship were pointing down, as often happened in heavy seas. Trials on land during the latter half of the 1970s proved the concept of the ramp, and showed that only relatively trivial modifications to the Sea Harrier’s undercarriage were required to allow it to use the new “ski jump” technique (Fozard, 1978; Davies & Thornborough, 1996).

The first installation of the “ski jump” on a ship was on the old light fleet carrier HMS Hermes, which was given a 12-degree ramp during a refit and took Sea Harriers onboard for trials in 1979. These trials showed that the concept would work at sea, although it had already been decided to add ramps to the Invincible class during build—although on the first two ships of the class, the ramp was at the lower angle of 7 degrees. This was due to the ships being fitted with a substantial anti-aircraft missile launcher in the bows, the firing arc of which required the lower-angle ramp. This reduced the benefits of the ramp, but still allowed a useful addition in payload or reduction in take-off run for the Sea Harrier (Brown & Moore, 2003).

Once HMS Invincible had been commissioned and began operating Sea Harriers, it became clear that the two systems had not been designed for each other. The dimensions of the ships' hangar had been defined by two main constraints—the need to change the rotor head of the Sea King helicopter and by the need for the ship's own gas turbine propulsion system uptakes to pass next to the hangar. This produced a "dumbbell" shaped hangar that was wider at its ends than in the middle section. While this was adequate for the Sea King, the absence of wing folding on the Sea Harrier did mean that they were already approaching the limits of the hangar width in this area. Even greater strains were caused by the Sea Harrier's support onboard the ship, with perhaps three times as much fuel, spares, etc., required for each Sea Harrier than for each Sea King helicopter. In addition, the need to remove the wing of the Sea Harrier in order to change its engine meant that a specialised hoist was installed in the hangar, with an engine change requiring the aircraft to be trestled and secured to the hangar floor. The entire engine change evolution could take several days, monopolising a major part of the hangar and reducing the scope for aircraft movements in the hangar (Andrews, 2009, February 12; Davies & Thornborough, 1996).

While these limitations were coming to light, there were benefits to using the Sea Harrier onboard the Invincible class. It quickly became apparent that the vectored thrust engine of the Sea Harrier allowed it to "back taxi" under its own power, reducing the requirement for tractors and towing gear and considerably speeding up the process of moving aircraft to and from parking areas on deck. This meant that landing and take-off cycles could be increased, adding to the other benefits of operating STOVL aircraft such as the ability to dispense with "go around" fuel margins, reduced weather minima and high sortie generation rates.

All these aspects were proven of value during the Falklands conflict in 1982, in which the Sea Harrier and Invincible class both proved their worth in a real conflict (Davies & Thornborough, 1996). Subsequently, both were updated, with the Sea Harrier receiving a new weapons system, and the Invincible class adapted with additional weapons and the ablity to operate a larger number of Sea Harriers (and later land-based Harriers). The anti-aircraft missile system was removed from the ships, allowing an increase in deck area and larger weapons magazines for the aircraft, and further operational experience has proven that these adaptations have been valuable.

Figure 3. Royal Navy Sea Harriers Operating from an Aircraft Carrier during the Falklands War
*Note the proximity of the deck crews, a problem in later studies for a Sea Harrier successor.
(Harrier.org.uk, 2009)

However, it can be seen from this brief and incomplete history that designing the ships and the aircraft as separate projects—only loosely associated during development—came at a considerable price in terms of reduced efficiency and difficulties in operation. These were offset by the personnel of the Royal Navy and Fleet Air Arm who proved adept at coping with these difficulties. However, the costs of the equipment line of development were considerable, and adding costs in terms of personnel, training and additions to the equipment to overcome deficiencies identified during use was undesirable, as was the in-built high logistics cost of the difficult nature of some Sea Harrier maintenance operations and the confined spaces of the Invincible class hangar.

Sea Harrier Replacement Design and Invincible Class

With the experience of the Falklands War and the emergence of new threats for the Soviet Union (notably the deployment of Soviet aircraft carriers, fighters and long-range maritime strike aircraft), meant that by the early 1980s, the Royal Navy was actively pursuing a Sea Harrier replacement programme, in addition to updating the earlier aircraft. One basic assumption was that such an aircraft would be in service during the lifetime of the Invincible class, so it had to be compatible with those ships. This allowed the opportunity to design new aircraft with the issues of operating from the Invincible class in mind, rather than evolving the aircraft design separately from the ship.

As part of the threat analysis and operational research into how to meet such a threat, work in the UK Ministry of Defence (MoD) into the characteristics of a Sea Harrier replacement showed that supersonic speed would be a valuable asset. In meeting a notional attack from Soviet forces, it was seen that a smaller number of supersonic aircraft could cover the threat than was the case with subsonic aircraft using similar sensors and weapons. For some threats, only supersonic speed in the aircraft could provide an adequate response. This issue of aircraft numbers was important as the relatively small size of the Invincible class (plus the ships' need to also accommodate anti-submarine helicopters) meant that the total number of aircraft carried was unlikely to exceed the number of Sea Harriers the ships could accommodate, about 8 STOVL aircraft (Pryce, 2008).

In industrial studies to develop a Sea Harrier successor aircraft (involving British Aerospace and Rolls Royce), the need to provide supersonic speed led to a number of design issues becoming the focus of much work. The most significant of these was that a much more powerful and energetic engine would be needed than that used in the Sea Harrier. This provided a number of environmental difficulties when operating aircraft onboard ships—as the noise, jet temperatures and velocities could adversely impact the deck environment of the ship as well as the aircraft itself to a significant extent (Pryce, 2008). One result of the work was that it was seen that it may be possible that when supersonic STOVL aircraft were hovering in advance of landing, the deck crew might need to use some form of refuge or shelter as the noise level could induce nausea and possible unconsciousness, and the high velocity jets of the aircraft could readily blow crew members overboard (Brooklands Museum Archive File HSA/SHR/047). Clearly, this would be unacceptable, as the role of the deck crew was to enable aircraft operations (see Figure 3).

The effort to obviate such potential risks in the design stage led to a number of propulsion systems and operating techniques that sought to reduce such adverse effects (Pryce, 2008). However, these brought with them a range of operational drawbacks as well—such as the loss of the ability to "back taxi" and the introduction of engines that were too large for the engine maintenance and storage spaces of the Invincible class. A visit by the aircraft design team from BAe to an Invincible class ship revealed further complications that had not been assumed in their design studies, such as ruts in the hangar deck that could mean that if the nose undercarriage of some designs went into such a rut, the tail of the aircraft could "scrape" the hangar roof—despite the ruts only being an inch or so deep. In addition, it was realised that the highly integrated avionics proposed for some of the new aircraft would require a complete re-arrangement of both the maintenance spaces of the ship and the trade structure of the maintenance personnel (Brooklands Museum Archive File HSA/SHR/047).

While these issues were not faced by all the new aircraft designs proposed (and many of them managed to successfully address the existing problems with the Sea Harrier, such as the difficult engine change evolution), it was apparent that the need for supersonic speed and the innate limitations of the Invincible class would cause problems. In the aircraft design studies, it was to be assumed that the ships were not to be modified with special devices such as deck blast deflectors to accommodate the new aircraft. It was discovered that a key limitation was the strength of the ski jump ramp of the ships, as the new aircraft were much heavier, and that strength limitations of the ramp, as well as in the undercarriage of the aircraft, meant that in some cases the aircraft could not take-off with a full load of fuel or weapons (National Archive File AVIA 6/25876).

While the aircraft designers were wrestling with these difficulties, additional analytical studies in the MoD and in BAe showed that further ship/aircraft interaction-dependent characteristics also provided limitations. With only a relatively small number of aircraft carried by the Invincible class, high levels of availability were essential to meet the threats assumed. While the aircraft could possibly be more reliable than the Sea Harrier, it became clear from assessment work of the deck and hangar movements of the aircraft onboard the ship that critical limitations on availability were imposed on all aircraft designs, with reductions in the number of aircraft actually available for operations disproportionately affected by these limitations (Pryce, 2008; Brooklands Museum Archive File HSA/SHR/047).

For example, the ability of the Sea Harrier to "back taxi" under its own power meant that it was able to move quickly into deck parking spaces. However, the configuration of the propulsion systems of the some of the proposed successor aircraft meant that this was not possible, so they would need to be towed around on deck. While a slower process in itself, the realisation that the turning circle of an aircraft plus tow bar and tractor may be much larger than a Sea Harrier meant that not only were manoeuvres slower, but also required greater free deck area to be carried out. Such free area may not be available as the deck was already congested—with many areas used for more than one purpose (see Figure 4), and a "traffic jam" situation would result. Similar problems arose when the size of the aircraft designs reached a point at which the size limits of the lifts or hangar were approached—narrow margins meant much more careful positioning was required, which the crew were likely to have to do much more slowly. It was realised that while crew training and possibly increase personnel numbers may make it possible ways to ameliorate such matters, it was difficult to accommodate additional crew onboard the ship and impossible to show the extent of training required to ensure high levels of availability (Pryce, 2008; Brooklands Museum Archive File HSA/SHR/047).

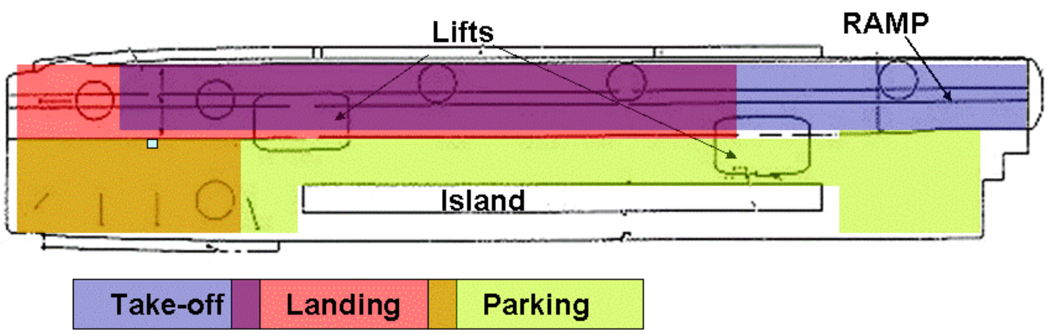

Figure 4. Invincible Class Deck Layout and Uses

(The colours show the different uses of the deck, and how these uses could overlap. An aircraft landing on the deck could slow down take-off operations if it was unable to clear the landing area or to park quickly (Brooklands Museum Archive File HSA/SHR/047).)

Once these ship-dependent aspects of replacing the Sea Harrier were looked into, it became clear that being able to design a new aircraft "around" the Invincible class as it already existed was extremely difficult—as the change in the threat that the new aircraft were intended to meet meant that the aircraft had features that the Invincible class found difficult to accommodate. Attempting to trade-off aircraft performance levels against the deck environment and "traffic" issues on deck also proved extremely difficult, and once wider issues such as the higher fuel/weapon loads of the new aircraft (leading to more frequent replenishment operations) were considered, the work led to the somewhat startling realisation that a new, "better" aircraft could lead to a reduction in capability compared to the Sea Harrier if it had to operate from an Invincible class ship (Brooklands Museum Archive File BAe/PRJ/065—NST.6464).

Harrier/Invincible Experience and CVF/JSF

Although the attempts at developing a replacement for the Sea Harrier foundered during the 1980s, the Royal Navy eventually transitioned to a force of Harrier aircraft operated in conjunction with the Royal Air Force in what is known as Joint Force Harrier. With heavy commitments to operations in Afghanistan, there has been only limited opportunity in recent years to deploy these aircraft aboard the two Invincible class ships still in service, but it is the intention of the Royal Navy to replace these vessels in the next decade with two much larger ships, under the CVF programme.

These vessels are intended to employ the Joint Strike Fighter (JSF), in particular the STOVL F-35B Lightning II version of the JSF. They will, therefore, be able to build upon the experience of STOVL operations at sea built up over many years by the Royal Navy, while at the same time benefitting from being able to design both systems in parallel in order to maximise the capabilities they can provide.

One clear lesson that has been adopted on the CVF programme is that a large ship is helpful in operating even STOVL aircraft, as it gives much more space for moving aircraft around, which has been a problem in past operations and studies. Based on the idea that "air is free and steel is cheap," this appears to be a welcome move, albeit one that may seem to reduce the need for using STOVL aircraft at all. Indeed, the CVF design has been developed so that it can be adapted for the later adoption of CTOL aircraft, including the CTOL version of the JSF. However, this would require not only a significant shift in UK procurement policy but also a re-assessment of all the lines of development for the CVF and JSF. As Figure 2 showed, the costs are distributed differently for the different types of aircraft, although basing them on versions of the JSF should reduce such differences.

Nevertheless, the current plan to deploy STOVL aircraft on the CVF means that the experience built up on the Harrier will be of use. This does not just depend on the service use of the Harrier, but also on research programmes that have used the aircraft. Most notable among these is the VAAC Harrier programme, which has been used to develop the flight control aspects of the STOVL JSF. In the Harrier family, the control of the aircraft was difficult because the pilot had a high work load when hovering the aircraft. For the JSF, the intention is that this can be reduced significantly, requiring much less training and greater flight safety, at the cost of a more complex flight control system.

Tests with the VAAC Harrier have revealed that the control system that came to be preferred from land-based trials needed some modifications when applied at sea (Denham, Krumenacker, D'Mello & Lewis, 2002). In addition, the VAAC Harrier has been used to develop the proposed Shipboard Rolling Vertical Landing (SRVL) technique that will allow the JSF to land at low speeds on the CVF, significantly increasing the "bring back" payload while reducing engine "wear and tear" (Rosa, 2008). While this should allow savings in terms of reduced maintenance as well as operations of the aircraft at higher weights and the deliverance of greater capability, there may be issues to address that may offset these savings in other lines of development, such as training for pilots and deck crew, and the development of additional deck lighting patterns and deck parking arrangements (Hodge & Wilson, 2008).

Further benefits from previous experience with the Harrier, and studies into replacing it, are shown by the adoption of a “ski jump” ramp for take-off. Despite the fact that the CVF is much larger than the Invincible class and that the JSF has a completely different propulsion system, the ramp still gives the same benefits as it did on earlier ships: boosting capability by increasing payloads and enhancing safety, as well as freeing up more deck area for aircraft parking and recovery (Fry, 2008; Rolfe, 2008). This is also assisted by the use of a jet blast deflector, the value of which was first indicated in the Sea Harrier replacement studies. Again, despite the larger size of CVF, the area of deck that it frees up for other uses is of great value, as is the enhancement of the safety of deck crew by reducing the chances of them being blown overboard (Morrison, Dockton & Underhill, 2008).

It is possible that the first aircraft to operate from the CVF will be those of Joint Force Harrier, as the ships may undertake trials (or be in operation) before the UK’s JSF fleet is ready to come aboard. If so, the experience of decades of Harrier operation will be able to be directly applied to the new ships, while new lessons about the greater capability of the larger ship could be directly related to the experience of using the Harrier onboard the Invincible class. In addition, such an opportunity could allow validation of some of the Harrier-based research work that has helped to underpin the JSF development. Although the equipment line of development subsumes many aspects of such research and technology programmes, there is little doubt that this work has provided a significant contribution to reducing costs across the lines of development.

Overview, Conclusions and Further Work

This paper has provided a limited view of the vast subject of operating STOVL aircraft from ships. Its aim has been to illustrate how the experiences of the “prosaic” issues covered matter in delivering capability, and how this capability is a product of the effect of these issues across the Defence Lines of Development.

In summary, it is hoped that this paper has shown that aircraft and aircraft carriers may benefit from being designed with each other in mind, but that they need to adapt to changing operational, technical and other circumstances (budgetary!). The timescale for designing, building and operating aircraft and ships extends over many decades, so it is simply not possible to design to a single “point.” Flexibility is an important attribute of both STOVL aircraft and aircraft carriers, with both able to contribute to capabilities independently of each other, but the flexibility of the combined system-of-systems that they deliver when brought together depends on an understanding of how the system functions over time. A key aspect of this is that it is extremely difficult, and probably undesirable, to tailor aircraft and ship designs to each other. This is because the lifecycles of each differ, and it may mean that they are then unable to contribute effectively to capability delivery when operated apart.

It is this difficult issue of optimising platforms as part of a flexible system that confronts acquisition managers. While it may be possible to use standards and protocols to ensure interoperability of digital systems or of weapon pylon attachments and other “lesser” mechanically based systems, at the level of complex, independent systems such as STOVL aircraft and aircraft carriers, it becomes a matter of having (at some point) to abandon the quest for an analytical “optimum” solution and instead to use judgement to decide on the best mix of platform characteristics and interactions to deliver capability. It is then up to the skills and bravery of service personnel to adapt the platforms, and to adapt to using them, in order to deliver a truly flexible range of capabilities using the systems they are given.

In order to support those involved in acquisition that need to use such judgement, as well to reduce the burden on service personnel later on, we will end with an outline suggestion for further research that may prove fruitful. Based on the researcher's own past efforts, and on discussions with practitioners in the field of aircraft and ship design, the researcher would suggest that attempts at understanding the real processes of designing ships and aircraft, understanding how design is done and not just assuming that it is done "by the book," offers a route to providing a basis for sound judgement. Design is a multi-faceted activity: but from an acquisition perspective, it would appear that understanding the early conceptual, or project design, stage matters most. This is because many of the irrevocable decisions about a platform or system are made at this stage, while trade-offs can be made against other platforms and systems—in an attempt to achieve desired capabilities—relatively cheaply in terms of actual expenditures.

However, doing this in isolation would miss important lessons, and it would appear that learning how to link current use of existing systems to the design of future ones would be useful too. If we can see how the assumptions and decisions of yesterday's acquisition experts have come to be used by today's service personnel, perhaps we can learn how to anticipate a little better the needs of the future. Hopefully this paper has made some small contribution to just such an endeavour.

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List of References

Andrews, D. (2003, September). A creative approach to ship architecture, *RINA International Journal of Maritime Technology.*

Andrews, D. (2009, February 12). [E-mail correspondence with researcher.]

Brooklands Museum Archive File BAe/PRJ/065—*NST.6464 Project Papers—Operational*

Brooklands Museum Archive File HSA/SHR/047—*Carrier Borne Air Operations*

Brown, D.K., & Moore, G. (2003). *Rebuilding the Royal Navy, warship design since 1945*. London: Chatham Publishing.

Davies, P.E., & Thornborough, A.M. (1996). *The Harrier story.* London: Arms & Armour Press.

Denham, J.W., Krumenacker, J.L., D'Mello, G.W., & Lewis, M. (2002, January 23-25). *Taking advanced STOVL flight control to sea: The VAAC follow-on research programme*. Paper Presented at the American Helicopter Society Aerodynamics, Acoustics and Test and Evaluation Technical Specialists Meeting, San Francisco, CA.

Fozard, J.W. (1978). *The Jet V/STOL Harrier: An evolutionary revolution in tactical air power* (AIAA Professional Study Series). Kingston Upon Thames, England: British Aerospace.

Fry, A. (2008). CVF Ski-jump ramp profile optimisation for F-35B. In *Proceedings of the International Powered Lift Conference, 22-24 July 2008*. London: Royal Aeronautical Society.

Harrier.org.uk. (2009). *Falklands War 25 years on—A nation remembers.* Retrieved from www.harrier.org.uk

Hodge, S.J., & Wilson, P.N. (2008). Operating JSF from CVF: The reality of simulation. In *Proceedings of the International Powered Lift Conference, 22-24 July 2008*. London: Royal Aeronautical Society.

Ministry of Defence (MoD). (2009, April). *Acquisition operating framework guide version 2.0.11*. Retrieved April 6, 2009, from http://www.aof.mod.uk/aofcontent/operational/business/capabilitymanagement/capabilitymanagement_whatis.htm

Morrison, E.J., Docton, M.K.R., & Underhill, R.M. (2008). Improving carrier operation through the application of CFD to the CVF design process. In *Proceedings of the International Powered Lift Conference, 22-24 July 2008*. London: Royal Aeronautical Society.

National Archive, File AVIA 6/25876—*Assessment of Vectored Thrust aircraft to AST.403 in the Maritime Role.*

Pryce, M.J. (2008). *Descartes and Locke at the drawing board—Project design and ASTOVL aircraft procurement* (D. Phil Thesis). Brighton, England: University of Sussex.

Rolfe, R. (2008). Ski-jump launch performance studies in DSTL. In *Proceedings of the International Powered Lift Conference, 22-24 July 2008*. London: Royal Aeronautical Society.

Rosa, M.R. (2008). The status of the shipboard rolling vertical landing technique. In *Proceedings of the International Powered Lift Conference, 22-24 July 2008*. London: Royal Aeronautical Society.

Stanford, J. (2008, July 23). JCA–The UK carrier strike solution. Presentation at the International Powered Lift Conference, London.

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